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Suppliers ranking by cross-efficiency evaluation in the presence of volume discount offers

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Abstract
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Suppliers ranking by cross-efficiency evaluation in the presence of volume discount offers

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Keywords: suppliers ranking; data envelopment analysis; DEA; volume discount; cross-efficiency.

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1 Introduction

Supply chain is an extension of logistics, which is mostly focused on related actions of physical products. Theoretically, supply chain management (SCM) consists of several connected logistics systems, which integrates the product and service moving into a system, and creates a continuous and seamless linking. Also, all the actions from raw materials to end customers for merchandises are fully coordinated. Due to such coordination, all the members inside the supply chain will be affected by other chain members either directly or indirectly. For instance, if upstream supplier provides defective raw materials, this will result in producing defective final products for downstream manufacturer. Definitely, this will also reduce the customer satisfaction (Kuo et al., 2010a). The short-term objective of SCM is primarily to increase productivity and reduce the entire inventory and the total cycle time, while the long-term objective is to increase customer satisfaction, market share, and profits for all organisations in the supply chain. To accomplish these objectives, tight coordination among the organisations in supply chains is needed (Lee et al., 2001).

Supplier selection is the basis of supply chain cooperation, and is also the key factor to improve the competitive power of a supply chain (Liu and Zhang, 2011). The success of a supply chain is highly dependent on selection of good suppliers (Hadi-Vencheh, 2011). Zolghadri et al. (in press) declare that, the design of a supply chain and partner selection in particular takes considerable effort in any organisation. The organisation needs to understand what is important to them in the selection of a particular supplier, i.e., they need to define the criteria by which to evaluate them. They should become aware of the variation between the different suppliers for that particular criterion but they should also understand what constitutes a good or a bad offer. Zeydan et al. (2010) argue that, there are a lot of factors in today's global market which forces companies to search for a competitive advantage by focusing on purchasing raw materials and component parts which represents the largest percentage of the total product cost. For instance, high technology products such as motor vehicles, railroad and transport equipment, machinery and equipment components, purchased materials and services account for up to 80% of the total product cost. Therefore, selecting the right suppliers is a key element to the procurement process and represents a major opportunity for companies to reduce costs. The objective of this study is to propose a ranking method of suppliers when they offer volume discounts.

The rest of this paper is organised as follows. In Section 2, literature review is presented. Section 3 introduces the method which selects the suppliers. In Section 4, the proposed algorithm for suppliers ranking is suggested. Numerical example and managerial implications are discussed in Sections 5 and 6, respectively. Finally, concluding remarks are discussed in Section 7.

2 Literature review

Some approaches have been used for supplier selection in the past. Lee et al. (2001) used analytic hierarchy process (AHP) for supplier selection and suggested a methodology leading to effective supplier management processes utilising information obtained from the supplier selection processes. For this methodology, they proposed the supplier selection and management system (SSMS) that includes purchasing strategy system, supplier selection system, and supplier management system. Wang et al. (2004) developed an integrated AHP and preemptive goal programming (GP)-based multi-criteria decision-making (MCDM) methodology to select the best set of multiple suppliers to satisfy capacity constraint. Sarkis and Talluri (2002) believe that, supplier evaluation factors would influence each other, and the internal interdependency need to be considered in the evaluation process. The authors applied analytic network process (ANP) to evaluate and select the best supplier with respect to organisational factors and strategic performance metrics, which consist of seven evaluating criteria.

For selecting vendors and allocating orders, an integrated fuzzy case-based reasoning (CBR) and mix integer programming model was proposed by Faez et al. (2009). Lin (2009) suggested an integrated fuzzy analytic network process-multi-objective linear programming (FANP-MOLP) approach for identifying top suppliers by considering the effects of interdependence among the selection criteria, as well as to achieve optimal allocation of orders among the selected suppliers. Kuo et al. (2010b) proposed integration of particle swarm optimisation (PSO)-based fuzzy neural network (FNN) and artificial neural network (ANN) for supplier selection. The authors developed an intelligent supplier decision support system which is able to consider both the quantitative and qualitative factors. It is composed of:

1 the collection of quantitative data such as profit and productivity

2 a PSO-based FNN to derive the rules for qualitative data

3 a decision integration model for integrating both the quantitative data and fuzzy knowledge decision to achieve the optimal decision.

Büyüközkan and Çifçi (2011) developed a novel approach based on FANP within multi-person decision-making schema under incomplete preference relations. The method not only makes sufficient evaluations using the provided preference information, but also maintains the consistency level of the evaluations. Finally, the paper analyses the sustainability of a number of suppliers in a real-life problem to demonstrate the validity of the proposed evaluation model. Amin et al. (2011) presented a decisional model for supplier selection which consists of two phases. In the first phase, quantified strengths, weaknesses, opportunities and threats (SWOT) analysis are applied for evaluating suppliers. The linguistic variables and triangular fuzzy numbers are used to quantify variables. In the second phase, a fuzzy linear programming model is applied to determine the order quantity.

In order to develop a flexible data access framework, and to support the partner selection activity, the combination of online analytical processing and CBR was proposed by Lau et al. (2005). Choy et al. (2004) developed an intelligent supplier relationship management system integrating a company's customer relationship management (CRM) system, supplier rating system and product coding system by the CBR technique to select preferred suppliers during the new product development process.

A mixed integer non-linear programming model to determine an optimal inventory policy that coordinates the transfer of items between different stages of a serial supply chain was proposed by Mendoza and Ventura (2010). This model can properly allocate orders among selected suppliers. Talluri and Baker (2002) presented a multi-phase mathematical programming approach for effective supply chain design. More specifically, they developed and applied a combination of multi-criteria efficiency models, based on the game theory concept, and linear and integer programming methods. Cormican and Cunningham (2007) discovered that reducing the number and improving the quality of suppliers resulted in increased quality, reduced lead time and a reduction in the number of errors and defects, by evaluating supplier performance from a large multinational organisation.

In recent years, data envelopment analysis (DEA) has been used to measure the efficiency of decision-making unit (DMU) in many different settings, such as efficiency and effectiveness in operations management (Aksezer and Benneyan, 2010; Goncharuk, 2007), SCM (Kim et al., 2011; Parkan and Wang, 2007; Das and Barman, 2010), sport industry (Boscá et al., 2009; Cooper et al., 2009), construction industry (El-Mashaleh et al., 2010; Baykasoglu et al., 2009), the farming industry (Mulwa et al., 2009) and the banking industry (Azadeh et al., 2010; Cooper et al., 2008; Paradia et al., 2010). DEA was applied by Weber (1996) in supplier evaluation problem. In this study, the criteria for selecting suppliers were significant reductions in costs, late deliveries and rejected materials. Weber et al. (2000) also presented an approach for evaluating the number of suppliers to employ in a procurement situation using multi-objective programming (MOP) and DEA. Talluri et al. (2006) suggested a chance-constrained data envelopment analysis (CCDEA) approach in the presence of multiple performance measures that are uncertain. Kang and Lee (2010) suggested a supplier performance evaluation model based on AHP and DEA methods. In this study, DEA is applied first to evaluate quantitative factors, and the results are transformed into pairwise comparison values for AHP analysis. Joo et al. (2009) used DEA to performance evaluation of existing suppliers. This study is an attempt to evaluate and score a focal company's existing suppliers of various commodities. The goal is to rate the suppliers comparatively using common measurable characteristics.

In this paper, DEA as a non-parametric and multiple criteria decision-making tool is used to suppliers' evaluation. DEA was first introduced by Charnes, Cooper, and Rhodes (CCR) in 1978 and it is a linear-programming-based methodology that uses multiple inputs and multiple outputs to calculate efficiency scores. The efficiency score for each DMU is defined as a weighted sum of outputs divided by a weighted sum of inputs, where all efficiencies are restricted to a range from 0 to 1. To avoid the potential difficulty in assigning these weights among various DMUs, a DEA model computes weights that give the highest possible relative efficiency score to a DMU while keeping the efficiency scores of all DMUs less than or equal to one under the same set of weights (Liu et al., 2000). However, sometimes in suppliers' evaluation problem, there may exists a particular situation. To encourage the buyers to order more, suppliers may offer volume discounts. While extensive research on economic order quantities with quantity discounts exists, only a few methods address the problem from the perspective of supplier selection and ranking. Dahel (2003) presented a multi-objective mixed integer programming approach to simultaneously determine the number of vendors to employ and the order quantities to allocate to these vendors in a multiple-product, multiple-supplier competitive sourcing environment. Arunkumar et al. (2006) proposed a GP model for supplier selection with quantity discounts. They converted the piecewise linear problem into an easier linear problem, thereby decreasing the complexity of the problem. Xia and Wu (2007) proposed an integrated approach of AHP improved by rough sets theory and multi-objective mixed integer programming to simultaneously determine the number of suppliers to employ and the order quantity allocated to these suppliers in the case of multiple sourcing, multiple products, with multiple criteria and with supplier's capacity constraints. Farzipoor Saen and Zohrehbandian (2008) demonstrated the advantages of applying DEA to consider suppliers volume discount offers in their evaluation process. In their study, a super-efficiency DEA model was used for complete ranking of suppliers. However, the proposed model suffers from infeasibility problem. To solve the infeasibility problem, Farzipoor Saen (2008) proposed an innovative algorithm for ranking suppliers in the presence of volume discount offers. As well, Farzipoor Saen (2009a, 2010) introduced a model which selects the best suppliers in the presence of cardinal and ordinal data in the conditions that they offer volume discounts.

The approaches presented by Farzipoor Saen and Zohrehbandian (2008), and Farzipoor Saen (2008, 2009a, 2010) had great contribution for considering volume discount offers through the DEA concept. However, all these models suffer from some limitations. Since, in traditional DEA, each DMU is free to decide which outputs and inputs to emphasise, it is common to have many DMUs that are relatively efficient. In addition, since each DMU has its own set of weights, all of its weight might be put on a single output and input and lead to an unrealistic weighting scheme. To overcome these problems, we propose to use the cross-efficiency method introduced by Sexton et al. (1986) and developed by Doyle and Green (1994) in volume discount environments. The main idea of cross-efficiency is to use DEA in a peer evaluation instead of a self-evaluation mode. Anderson et al. (2002) argue that cross-evaluation has two main advantages. First, it usually creates a unique ordering among the DMUs. With cross-evaluation, since each DMU is rated not only by its own weighting scheme but the schemes of the others also, this amalgamation of weighting schemes makes it far more difficult to have ties and, in effect, creates a unique ordering in practice. Second, cross-evaluation appears to eliminate unrealistic weighting schemes that might be used by the DMUs. Under a cross-evaluation, once the DMU has a chosen weighting scheme which has been applied to all DMUs, the efficiency value given to each DMU is set aside forming a cross-efficiency matrix. Once the matrix is filled, each DMU has not only its own self-evaluation but also the peer evaluations it has received via the other DMUs in the sample. The average across self and peer evaluations represent a DMU's cross-efficiency value. A DMU which has a high cross-efficiency value has, therefore, passed a more rigorous test since it can not only make itself look good but is considered efficient by the majority of its peers.

The above discussions make it more reasonable to use the cross-efficiency approach when suppliers offer volume discounts. The objective of this paper is to propose a cross-efficiency model for ranking suppliers in volume discount environments.

To the best of knowledge of authors, there is not any reference that uses cross-efficiency model in volume discount environments.

3 Proposed method

Suppose there is a set of n peer DMUs, $\{DMU_j: j = 1, 2, \dots, n\}$, which produce multiple outputs $y_{rj}(r = 1, 2, \dots, s)$, by utilising multiple inputs $x_{ij}(i = 1, 2, \dots, m)$. The used nomenclatures in this paper are summarised in Table 1.

Table 1 The nomenclatures

DMU_o	The decision-making unit under investigation
n	The set of DMUs (suppliers)
$j = 1, \dots, n$	Collection of DMUs
$r = 1, \dots, s$	The set of outputs
$i = 1, \dots, m$	The set of inputs
y_{ro}	r^{th} output of DMU_o
y_{rj}	r^{th} output of DMU_j
x_{io}	i^{th} input of the DMU_o
x_{ij}	The i^{th} input of DMU_j
u_r	The weight for r^{th} output
v_i	The weight for i^{th} input
E_{oj}	Shows the relative efficiency of DMU_j with the set of optimal weights for inputs and outputs of DMU_o
E_{oo}	Is the efficiency score of DMU_o by its own set of optimal weights
c_{jk}	Unit price quoted by supplier j in discount interval k
d_j	Discount interval offered by supplier j

The input-oriented CCR model evaluates the supplier under investigation (DMU_o) ($o = 1, \dots, n$) by solving Model (1).

$$
\begin{aligned}
&E_{oo} = \max h_A = \sum_{r=1}^{s} u_r y_{ro} \\
&s.t. \\
&\sum_{i=1}^{m} v_i x_{io} = 1, \\
&\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, ..., n \\
&v_i \geq 0, \qquad i = 1, 2, ..., m, \\
&u_r \geq 0, \qquad r = 1, 2, ..., s.
\end{aligned} \tag{1}
$$

As mentioned earlier, by using Model (1) it is common to have many DMUs that are relatively efficient. In addition, since each DMU has its own set of weights, all of its weight might be put on a single output and input and lead to unrealistic weighting schemes.

At this juncture, to create a unique ordering among the efficient DMUs and to eliminate unrealistic weighting schemes in Model (1), we use the cross-efficiency form of this model. For each DMU_o (o = 1, ..., n), in Model (1), we can obtain a set of optimal weights (multipliers) $\left(u_r^*, v_i^*\right)$. Using these set of weights, the cross-efficiency for any DMUj (j = 1, …, n), is then calculated as:

$$E_{oj} = \frac{\sum_{r=1}^{s} u_{ro}^* y_{rj}}{\sum_{i=1}^{m} v_{io}^* x_{ij}} \qquad o, j = 1, ..., n \tag{2}$$

where E_{oj} shows the relative efficiency of DMUj with optimal weights for inputs and outputs of DMU_o. One can compute the average of the efficiencies in each column to get a measure of how the DMUs associated with the column are rated by the rest of the DMUs. Good operating practices more likely to be exhibited by relatively efficient DMUs offering high average efficiencies in their associated columns in the cross-efficiency matrix. Since Model (1) will be run n times for n DMUs, respectively, each DMU will get n efficiency scores, which construct a matrix, called cross-efficiency matrix. For DMU_j (j = 1, …, n), the average of all E_{oj}(o = 1, …, n), can be used as an efficiency measure for DMU_j, and will be referred to as the cross-efficiency score for DMU_j. The average is shown as below.

$$\bar{E}_j = \frac{1}{n} \sum_{o,\, j=1}^{n} E_{oj} \tag{3}$$

The non-uniqueness of the DEA optimal weights possibly reduces the usefulness of the cross-efficiency which considers volume discount offers. To overcome this problem, Doyle and Green (1994) suggested the use of aggressive and benevolent cross-evaluation. A cross-evaluation is aggressive/benevolent in the sense that it selects a set of weights which not only maximise the efficiency of a particular DMU under evaluation, but also minimise/maximise the efficiencies of all other DMUs in some sense. We run the aggressive formulation of Model (1) and show it as Model (4). Note that the benevolent formulation has the same set of constraints except that the objective function is maximised.

$$
\begin{aligned}
&\text{Min } h_B = u_r \sum\nolimits_{j \neq 0} y_{rj} \\
&s.t. \\
&v_i \sum\nolimits_{j \neq 0} x_{ij} = 1, \\
&\sum\nolimits_{r=1}^{s} u_r y_{rj} - \sum\nolimits_{i=1}^{m} v_i x_{ij} \leq 0, \qquad j \neq 0, \\
&\sum\nolimits_{r=1}^{s} u_r y_{ro} - E_{oo} \left(\sum\nolimits_{i=1}^{m} v_i x_{io} \right) = 0, \qquad j = 1, 2, \ldots, n, \\
&v_i \geq 0, \qquad i = 1, 2, \ldots, m, \\
&u_r \geq 0, \qquad r = 1, 2, \ldots, s.
\end{aligned}
\tag{4}
$$

where E_{oo} is the efficiency of DMU$_o$ obtained from Model (1). Now the algorithm which can rank the suppliers in the presence of volume discount offers is introduced. In this paper, supplier is considered as DMU. Consider a procurement situation that suppliers provide different levels of price, product quality, delivery performance, etc. Also, depending on the buyer's purchase quantity, supplier j offers a volume discount having d_j discount intervals according to business volume.

4 Algorithm for suppliers ranking

In this section, the algorithm proposed by Farzipoor Saen (2008) is presented. The steps are as follow:

1 Determine quantity of demand

In this step, the buyer determines the desired quantity of material. To determine the demand quantity the techniques such as material requirement planning (MRP) and ANNs can be used.

2 Identify the price vector for the desired quantity

In this step, for each supplier, piecewise linear function of material price is partitioned so that the material price of each supplier in the related interval becomes a constant parameter, i.e., intersections of material price breaks of all suppliers are computed. Assume that there are three suppliers. Figure 1 shows this step graphically.

3 Apply Model (1) for each intersection

In this step, with respect to material price in each intersection (including n suppliers) and other criteria such as quality, delivery performance, etc.; an appropriate DEA model is applied. The suppliers in this step will be categorised in two sections of efficient and inefficient suppliers.

4 To find the optimal weights of variables, run Model (4).

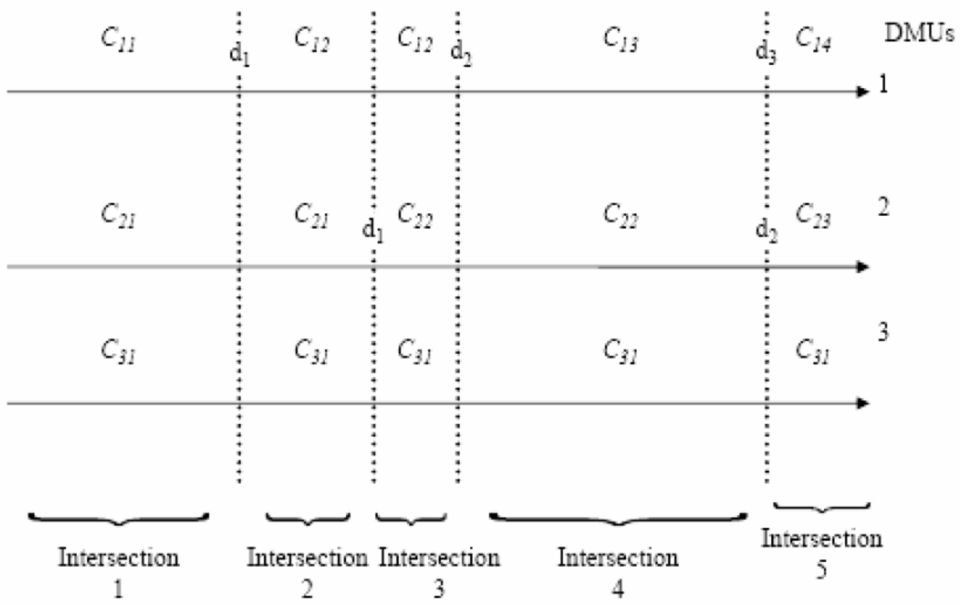
5 To construct the cross-efficiency matrix, use the weights of variables derived from previous step and calculate formula (2).

6 To derive the final peer appraisal efficiency score of suppliers, calculate formula (3).

7 To recognise the maverick suppliers, calculate formula (5).

8 Interpret the results.

Figure 1 Intersections of price breaks of three suppliers



Source: Farzipoor Saen (2008)

5 Numerical example

In order to demonstrate the application of the proposed model, the dataset for this study is taken from Farzipoor Saen (2008). The inputs for selecting suppliers include price (P) and number of shipments (NS). The outputs utilised in the study are number of bills received from the supplier without errors (NB) and number of shipments to arrive on time (NOT). The price breaks for ordered quantity are given in Table 2, according to the discount range of each supplier. Table 3 depicts other attributes of suppliers.

First, assume that the buyer's demand is 9 tons. Next, intersections of price breaks for all suppliers are determined. Table 4 shows the related price vector of 9 tons.

Table 5 shows the efficiency scores of suppliers, using Model (1), and their ranking results. Using this model, each supplier seeks to maximise its efficiency score by choosing a set of optimal weights for all inputs and outputs. In this evaluation, the best suppliers are suppliers 2, 3, 5, 6, and 12 which their efficiency scores equal to unity.

Table 2 Price breaks

Supplier no. (DMU)	*Ranges (tons)*	*Price ($)*
1	[0, 10]	10
	(10, 15]	9
	(15, +∞)	7
2	[0, 5]	8
	(5, +∞)	5
3	[0, 6]	20
	(6, 10]	18
	(10, 15]	15
	(15, +∞)	13
4	[0, +∞)	12
5	[0, 8]	10
	(8, +∞)	9
6	[0, 11]	15
	(11, +∞)	12
7	[0, +∞)	13
8	[0, 4]	11
	(4, 7]	10
	(7, +∞)	8
9	[0, 12]	8
	(12, +∞)	7
10	[0, 15]	14
	(15, 20]	12
	(20, +∞)	9
11	[0, +∞)	11
12	[0, +∞)	14

Table 3 Dataset for 12 suppliers

Supplier no. (DMU)	*Input*	*Outputs*	
	NS x_{2j}	*NB* y_{1j}	*NOT* y_{2j}
1	197	90	187
2	198	130	194
3	229	200	220
4	169	100	160
5	212	173	204
6	197	170	192
7	209	60	194
8	203	145	195
9	208	150	200
10	203	90	171
11	207	100	174
12	234	200	209

Table 4 Related price vector of 9 tons

Supplier no. (DMU)	*Price ($)* x_{1j}
1	10
2	5
3	18
4	12
5	9
6	15
7	13
8	8
9	8
10	14
11	11
12	14

Table 5 Efficiency scores and ranking using Model (1)

Supplier no. (DMU)	*Efficiency scores derived by Model (1)*	*Ranking*
1	0.969	8
2	1	1
3	1	1
4	0.966	9
5	1	1
6	1	1
7	0.947	10
8	0.984	7
9	0.986	6
10	0.860	11
11	0.858	12
12	1	1

Since Model (1) cannot give a complete ranking and there are ties among five efficient suppliers, the cross-efficiency evaluation is used to derive suppliers' complete ranking. Table 6 shows the cross-efficiency matrix.

Table 7 shows the suppliers final efficiency scores and final rankings derived by the cross-efficiency approach. As the last column of this table shows, supplier 2 is the most efficient supplier and is the first candidate for selection.

To statistically compare the results of the suppliers self and peer evaluations, the non-parametric Spearman correlation analysis between their ranking results is shown in Table 8.

Table 6 Matrix of cross-efficiency

Supplier no. (DMU)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
1	*0.9688*	1.0000	0.9805	0.9663	0.9821	0.9947	0.9474	0.9804	0.9814	0.8597	0.8579	0.9116
2	0.4820	*1.0000*	0.3150*	0.3436	0.5842	0.3299	0.3846	0.6282	0.6443	0.3148	0.4077	0.3848
3	0.5231	0.7518	*1.0000*	0.6775	0.9344	0.9881	0.3287	0.8179	0.8257	0.5076	0.5531	0.9786
4	0.9688	1.0000	0.9805	*0.9663*	0.9821	0.9947	0.9474	0.9804	0.9814	0.8597	0.8579	0.9116
5	0.5116	1.0000	0.7587	0.5475	*1.0000*	0.7648	0.2873	0.9067	0.9257	0.4175	0.5279	0.8747
6	0.7051	0.9000	1.0000	0.7898	1.0000	*1.0000*	0.5573	0.9227	0.9296	0.6411	0.6836	0.9837
7	0.9688	1.0000	0.9805	0.9663	0.9821	0.9947	*0.9474*	0.9804	0.9814	0.8597	0.8579	0.9116
8	0.9268	1.0000	0.9879	0.9355	1.0000	1.0000	0.8755	*0.9840*	0.9864	0.8203	0.8321	0.9347
9	0.9268	1.0000	0.9879	0.9355	1.0000	1.0000	0.8755	0.9840	*0.9864*	0.8203	0.8321	0.9347
10	0.9688	1.0000	0.9805	0.9663	0.9821	0.9947	0.9474	0.9804	0.9814	*0.8597*	0.8579	0.9116
11	0.9688	1.0000	0.9805	0.9663	0.9821	0.9947	0.9474	0.9804	0.9814	0.8597	*0.8579*	0.9116
12	0.5402	0.8004	1.0000	0.6834	0.9745	0.9908	0.3350	0.8560	0.8653	0.5133	0.5696	*1.0000*

Notes: *0.3150 represents the cross-efficiency score of supplier #3 in terms of optimal weights of supplier #2.
**Italic numbers in the leading diagonal are the simple efficiencies derived by Model (1).

Table 7 Results of evaluation via cross-efficiency approach

Supplier no. (DMU)	*Cross-efficiency scores*	*Rank*
1	0.7883	9
2	0.9543	1
3	0.9127	6
4	0.8120	8
5	0.9503	2
6	0.9206	4
7	0.6984	11
8	0.9168	5
9	0.9225	3
10	0.6945	12
11	0.7246	10
12	0.8874	7

Table 8 Correlation coefficient between suppliers self and peer evaluations ranking

			Self-evaluation	*Peer evaluation*
Spearman's rho	Self-evaluation	Correlation coefficient	1	0.7819
	Peer evaluation	Correlation coefficient	0.7819	1

Table 9 False positiveness of the suppliers

Supplier no. (DMU)	*FPI*
1	22.92275
2	4.78885
3	9.565027
4	18.96552
5	5.229927
6	8.62481
7	35.59565
8	7.329843
9	6.883469
10	23.83009
11	18.41016
12	12.68875

As correlation coefficient between the results of two approaches, at significant level of 0.01, is 0.7819, there is a significant relationship between their results. However, since ranking of some suppliers such as suppliers 3 and 12 in peer evaluation has considerably decreased, applying the model proposed in this paper is necessary. These changes happen because suppliers in their self-evaluations are free to choose which inputs and outputs to emphasise.

Here, using the maverick index in the cross-efficiency evaluation suggested by Doyle and Green (1994) or the false positive index (FPI) defined by Baker and Talluri (1997), we can indicate the importance of selecting suppliers in a peer evaluation mode instead of self-evaluation.

$$\text{FPI} = \frac{E_{dd} - E_{jd}}{E_{jd}} \times 100 \tag{5}$$

We can use the FPI in identifying the maverick suppliers. They are those suppliers which enjoy the greatest relative increment when shifting from peer evaluation to self-evaluation. Note that the higher FPI, the more false positive (maverick) is DMU_o. Table 9 shows the amount of the FPI for the 12 suppliers. Supplier # 7 with the 35.59565 of FPI is assumed as the most maverick supplier and will enjoy the greatest relative increment when shifting from peer evaluation to self-evaluation.

6 Managerial implications

Managing the purchasing task in the supply chain has been a challenge in the last decade for many companies. The need to obtain a global competitive edge on the supply side has increased significantly. Particularly for companies who spend a high percentage of their sales revenue on parts and material supplies, and whose material costs represent a larger portion of total costs, savings from supplies are of great importance (Farzipoor Saen, 2009b). As Liao and Kao (2010) argue, supplier selection is one of the critical decision-making activities to obtain competitive advantage and achieve supply chain objectives. To reach this purpose, the purchasing managers should apply the best method to solve supplier selection problem. Supplier selection is the process of finding suitable suppliers from the set of alternative suppliers who can be strategic partners to the organisation and provide the right quality of product or services at the right price and at the right time (Mahpatra, 2011). To this end, this paper presented a usage of DEA cross-efficiency evaluation to achieve the peer appraisal of suppliers instead of their self-appraisal when suppliers offer volume discounts.

7 Concluding remarks

With the increasing significance of the purchasing function, purchasing decisions become more important. As organisations become more dependent on suppliers the direct and indirect consequences of poor decision-making become more severe. For example, in industrial companies, purchasing share in the total turnover typically ranges between 50-90% (Telgen, 1994). In addition, several developments further complicate purchasing decision-making (Boer et al., 2001).

In this paper, DEA as a multiple criteria decision-making tool is used to evaluate and select suppliers. In applying DEA, we discussed about a particular situation in which suppliers offer volume discounts to foster the purchase of large volumes. In the meantime, appearance of a new discount pricing schedule entitled 'volume discount' becomes a major obstacle for procurement managers in finding the best purchasing strategy. In the context of volume discount, a supplier offers discounts on total amount of volume purchased from the supplier (Farzipoor Saen, 2010). To derive a complete ranking of suppliers and eliminate unrealistic weighting schemes among suppliers, the cross-efficiency approach is used. The supplier selection approach developed in this paper includes a number of attractive features, as below:

- the proposed model evaluates suppliers in a multi-criteria context
- supplier selection is a straightforward process carried out by the proposed model
- to achieve the peer appraisal of suppliers instead of their self-appraisal, the cross-efficiency model in volume discount environments is used
- the proposed model can be easily computerised, enabling it to serve as a decision-making tool to assist decision-makers.

However, limitation of proposed model in this paper is radial assumption of the model. In DEA, non-zero input and output slacks are very likely to reveal themselves after the radial efficiency score improvement. Often, the non-zero slack values reveal a considerable amount of inefficiency. Therefore, in order to fully measure the inefficiency in DMUs performance, it is essential to consider the inefficiency represented by the non-zero slacks in the existence of volume discounts.

The problem considered in this study is at the initial stage of investigation and further researches can be done based on the results of this paper. Some of them are as below:

- Similar research can be repeated in the presence of undesirable outputs.
- Similar research can be repeated in the presence of stochastic data.
- This study used the proposed model for ranking suppliers. It seems that more fields (e.g., technology ranking, personnel ranking, market ranking, etc.) can be applied.

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References

Aksezer, C.S. and Benneyan, J.C. (2010) 'Assessing the efficiency of hospitals operating under a unique owner: a DEA application in the presence of missing data', *International Journal of Services and Operations Management*, Vol. 7, No. 1, pp.53–75.

Amin, S.H., Razmi, J. and Zhang, G. (2011) 'Supplier selection and order allocation based on fuzzy SWOT analysis and fuzzy linear programming', *Expert Systems with Applications*, Vol. 38, No. 1, pp.334–342.

Anderson, T.R., Hollingsworth, K. and Inman, L. (2002) 'The fixed weighting nature of a cross-evaluation model', *Journal of Productivity Analysis*, Vol. 17, No. 3, pp.249–255.

Arunkumar, N., Karunamoorthy, L., Anand, S. and Ramesh, B.T. (2006) 'Linear approach for solving a piecewise linear vendor selection problem of quantity discounts using lexicographic method', *The International Journal of Advanced Manufacturing Technology*, Vol. 28, Nos. 11–12, pp.1254–1260.

Azadeh, A., Ghaderi, S.F., Mirjalili, M. and Moghaddam, M. (2010) 'A DEA approach for ranking and optimisation of technical and management efficiency of a large bank based on financial indicators', *International Journal of Operational Research*, Vol. 9, No. 2, pp.160–187.

Baker, P.C. and Talluri, S. (1997) 'A closer look at the use of data envelopment analysis for technology selection', *Computers & Industrial Engineering*, Vol. 32, No. 1, pp.101–108.

Baykasoglu, A., Ozbay, E., Gogus, M.T. and Oztas, A. (2009) 'Contractor selection with multi criteria decision support tools', *International Journal of Industrial and Systems Engineering*, Vol. 4, No. 2, pp.174–197.

Boer, L.D., Labro, E. and Morlacchi, P. (2001) 'A review of methods supporting supplier selection', *European Journal of Purchasing & Supply Management*, Vol. 7, No. 2, pp.75–89.

Boscá, J.E., Liern, V., Martínez, A. and Sala, R. (2009) 'Increasing offensive or defensive efficiency? An analysis of Italian and Spanish football', *Omega*, Vol. 37, No. 1, pp.63–78.

Büyüközkan, G. and Çifçi, G. (2011) 'A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information', *Computers in Industry*, Vol. 62, No. 2, pp.164–174.

Charnes, A., Cooper, W.W. and Rhodes, E. (1978) 'Measuring the efficiency of decision making units', *European Journal of Operational Research*, Vol. 2, No. 6, pp.429–444.

Choy, K.L., Lee, W.B. and Lo, V. (2004) 'Development of a case based intelligent supplier relationship management system-linking supplier rating system and product coding system', *Supply Chain Management: International Journal*, Vol. 9, No. 1, pp.86–101.

Cooper, W.W., Ruefli, T.W., Deng, H., Wu, J. and Zhang, Z. (2008) 'Are state-owned banks less efficient? A long- vs. short-run data envelopment analysis of Chinese banks', *International Journal of Operational Research*, Vol. 3, No. 59, pp.533–556.

Cooper, W.W., Ruiz, J.L. and Sirvent, I. (2009) 'Selecting non-zero weights to evaluate effectiveness of basketball players with DEA', *European Journal of Operational Research*, Vol. 195, No. 2, pp.563–574.

Cormican, K. and Cunningham, M. (2007) 'Supplier performance evaluation: lessons from a large multinational organization', *Journal of Manufacturing Technology Management*, Vol. 18, No. 4, pp.352–366.

Dahel, N.E. (2003) 'Vendor selection and order quantity allocation in volume discount environments', *Supply Chain Management: An International Journal*, Vol. 8, No. 4, pp.335–342.

Das, D. and Barman, D. (2010) 'An AHP framework of supplier evaluation with reference to high-value and critical items: a case study', *International Journal of Services and Operations Management*, Vol. 7, No. 4, pp.465–482.

Doyle, J. and Green, R. (1994) 'Efficiency and cross efficiency in DEA: derivations, meanings and the uses', *Journal of the Operational Research Society*, Vol. 45, No. 5, pp.567–578.

El-Mashaleh, M., Rababeh, S.H. and Hyari, K.H. (2010) 'Utilizing data envelopment analysis to benchmark safety performance of construction contractors', *International Journal of Project Management*, Vol. 28, No. 1, pp.61–67.

Faez, F., Ghodsypour, S.H. and O'Brien, C. (2009) 'Vendor selection and order allocation using an integrated fuzzy case-based reasoning and mathematical programming model', *International Journal of Production Economics*, Vol. 121, No. 2, pp.395–408.

Farzipoor Saen, R. (2008) 'Using super-efficiency analysis for ranking suppliers in the presence of volume discount offers', *International Journal of Physical Distribution & Logistics Management*, Vol. 38, No. 8, pp.637–651.

Farzipoor Saen, R. (2009a) 'Suppliers selection in volume discount environments in the presence of both cardinal and ordinal data', *International Journal of Information Systems and Supply Chain Management*, Vol. 2, No. 1, pp.69–80.

Farzipoor Saen, R. (2009b) 'Using data envelopment analysis for ranking suppliers in the presence of nondiscretionary factors', *International Journal of Procurement Management*, Vol. 2, No. 3, pp.229–243.

Farzipoor Saen, R. (2010) 'A new algorithm for ranking suppliers in volume discount environments', *Asia Pacific Management Review*, Vol. 15, No. 3, pp.341–358.

Farzipoor Saen, R. and Zohrehbandian, M. (2008) 'A data envelopment analysis approach to supplier selection in volume discount environments', *International Journal of Procurement Management*, Vol. 1, No. 4, pp.472–488.

Goncharuk, A.G. (2007) 'Using the DEA in efficiency management in industry', *International Journal of Productivity and Quality Management*, Vol. 2, No.2, pp.241–262.

Hadi-Vencheh, A. (2011) 'A new nonlinear model for multiple criteria supplier-selection problem', *International Journal of Computer Integrated Manufacturing*, Vol. 24, No. 1, pp.32–39.

Joo, S., Jr, Messer, G.H.M. and Bradshaw, R. (2009) 'The performance evaluation of existing suppliers using data envelopment analysis', *International Journal of Services and Operations Management*, Vol. 5, No. 4, pp.429–443.

Kang, H. and Lee, A. (2010) 'A new supplier performance evaluation model; a case study of integrated circuit packaging companies', *Kybernetes*, Vol. 39, No. 1, pp.37–54.

Kim, J.H., Youn, S. and Roh, J.J. (2011) 'Green supply chain management orientation and firm performance: evidence from South Korea', *International Journal of Services and Operations Management*, Vol. 8, No. 3, pp.283–304.

Kuo, R.J., Lee, L.Y. and Hu, T. (2010a) 'Developing a supplier selection system through integrating fuzzy AHP and fuzzy DEA: a case study on an auto lighting system company in Taiwan', *Production Planning & Control*, Vol. 21, No. 5, pp.468–484.

Kuo, R.J., Hong, S.Y. and Huang, Y.C. (2010b) 'Integration of particle swarm optimization-based fuzzy neural network and artificial neural network for supplier selection', *Applied Mathematical Modelling*, Vol. 34, No. 12, pp.3976–3990.

Lau, H., Lau, P., Fung, R., Chan, F. and Ip, R. (2005) 'A virtual case benchmarking scheme for vendors, performance assessment', *Benchmarking: International Journal*, Vol. 12, No. 1, pp.61–80.

Lee, E., Ha, S. and Kim, S. (2001) 'Supplier selection and management system considering relationships in supply chain management', *IEEE Transactions on Engineering Management*, Vol. 48, No. 3, pp.307–318.

Liao, C. and Kao, H. (2010) 'Supplier selection model using Taguchi loss function, analytical hierarchy process and multi-choice goal programming', *Computers & Industrial Engineering*, Vol. 58, No. 4, pp.571–577.

Lin, R.H. (2009) 'An integrated FANP-MOLP for supplier evaluation and order allocation', *Applied Mathematical Modelling*, Vol. 33, No. 6, pp.2730–2736.

Liu, J., Ding, F.Y. and Lall, V. (2000) 'Using data envelopment analysis to compare suppliers for supplier selection and performance improvement', *Supply Chain Management: An International Journal*, Vol. 5, No. 3, pp.143–150.

Liu, P. and Zhang, X. (2011) 'Research on the supplier selection of a supply chain based on entropy weight and improved ELECTRE-III method', *International Journal of Production Research*, Vol. 49, No. 3, pp.637–646.

Mahpatra, S.S. (2011) 'Supplier selection in supply chain management: a fuzzy multi-criteria decision-making approach', *International Journal of Services and Operations Management*, Vol. 8, No.1, pp.108–126.

Mendoza, A. and Ventura, J.A. (2010) 'A serial inventory system with supplier selection and order quantity allocation', *European Journal of Operational Research*, Vol. 207, No. 3, pp.1304–1315.

Mulwa, R., Emrouznejad, A. and Muhammad, L. (2009) 'Economic efficiency of smallholder maize producers in Western Kenya: a DEA meta-frontier analysis', *International Journal of Operational Research*, Vol. 4, No. 3, pp.250–267.

Paradia, J.C., Rouatt, S. and Zhu, H. (2010) 'Two-stage evaluation of bank branch efficiency using data envelopment analysis', *Omega*, Vol. 39, No. 1, pp.99–109.

Parkan, C. and Wang, J. (2007) 'Gauging the performance of a supply chain', *International Journal of Productivity and Quality Management*, Vol. 2, No. 2, pp.141–176.

Sarkis, J. and Talluri, S. (2002) 'A model for strategic supplier selection', *Journal of Supply Chain*, Vol. 38, No. 1, pp.18–28.

Sexton, T.R., Silkman, R.H. and Hogan, A.J. (1986) 'Data envelopment analysis: critique and extensions', in Silkman, R.H. (Ed.): *Measuring Efficiency: An Assessment of Data Envelopment Analysis*, Chapter 4, pp.73–105, Jossey-Bass, San Francisco.

Talluri, S. and Baker, R.C. (2002) 'A multi-phase mathematical programming approach for effective supply chain design', *European Journal of Operational Research*, Vol. 141, No. 3, pp.544–558.

Talluri, S., Narasimhan, R. and Nair, A. (2006) 'Vendor performance with supply risk: a chance-constrained DEA approach', *International Journal of Production Economics*, Vol. 100, No. 2, pp.212–222.

Telgen, J. (1994) 'Inzicht en overzicht:de uitdagigen van besliskundeen inkoopmanagement', Academical adress at the University of Twente, Enschede, Netherlands.

Wang, G., Huang, S.H. and Dismukes, J.P. (2004) 'Product-driven supply chain selection using integrated multi-criteria decision-making methodology', *International Journal of Production Economics*, Vol. 91, No. 1, pp.1–15.

Weber, C.A. (1996) 'A data envelopment analysis approach to measuring vendor performance', *Supply Chain Management: An International Journal*, Vol. 1, No. 1, pp.28–39.

Weber, C.A., Current, J. and Desai, A. (2000) 'An optimization approach to determining the number of vendors to employ', *Supply Chain Management: An International Journal*, Vol. 5, No. 2, pp.90–98.

Xia, W. and Wu, Z. (2007) 'Supplier selection with multiple criteria in volume discount environments', *Omega*, Vol. 33, No. 5, pp.494–504.

Zeydan, M., Çolpan, C. and Çobanoglu, C. (2010) 'A combined methodology for supplier selection and performance evaluation', *Expert Systems with Applications*, Vol. 38, No. 3, pp.2741–2751.

Zolghadri, M., Eckert, C., Zouggar, S. and Girard, P.H. (in press) 'Power-based supplier selection in product development projects', *Computers in Industry*, Vol. 62, No. 5, pp.487–500.